

GM Crops & Food >
Biotechnology in Agriculture and the Food Chain
Volume 8, 2017 - [Issue 3](#)

 Open access

19,331 Views | 46 CrossRef citations to date | 38 Altmetric

Listen

Research Papers

Farm income and production impacts of using GM crop technology 1996–2015

Graham Brookes  & Peter Barfoot 

Pages 156-193 | Received 10 Feb 2017, Accepted 04 Apr 2017, Accepted author version posted online: 08 May 2017, Published online: 19 Jun 2017

 Cite this article  <https://doi.org/10.1080/21645698.2017.1317919>

 Check for updates

 Full Article

 Figures & data

 References

 Citations

 Metrics

 Licensing

 Reprints & Permissions

 View PDF

 Share

ABSTRACT

This paper provides an assessment of the value of using genetically modified (GM) crop technology in agriculture at the farm level. It follows and updates earlier annual studies which examined impacts on yields, key variable costs of production, direct farm (gross) income and impacts on the production base of the 4 main crops of soybeans, corn, cotton and canola. The commercialisation of GM crops has occurred at a rapid rate since the mid 1990s, with important changes in both the overall level of adoption and impact occurring in 2015. This annual updated analysis shows that there continues to be very significant net economic benefits at the farm level amounting to \$15.4 billion in 2015 and \$167.8 billion for the 20 year period 1996–2015 (in nominal terms). These gains have been divided 49% to farmers in developed countries and 51% to farmers in

gains with the remaining 28% coming from cost savings. The technology has also made important contributions to increasing global production levels of the 4 main crops, having, for example, added 180 million tonnes and 358 million tonnes respectively, to the global production of soybeans and maize since the introduction of the technology in the mid 1990s.

KEYWORDS:

cost genetically modified crops income production yield

INTRODUCTION

2015 represents the twentieth year of widespread cultivation of crops containing genetically modified (GM) traits, with the global planted area of GM-traited crops at about 172 million hectares.

During this 20-year period, there have been many papers assessing the farm level 'economic' and farm income impacts associated with the adoption of this technology. The authors of this paper have, since 2005, engaged in an annual exercise to aggregate and update the sum of these various studies, and where possible and appropriate, to supplement this with new analysis. The aim of this has been to provide an up to date and as accurate as possible assessment of some of the key farm level 'economic' impacts associated with the global adoption of crops containing GM traits. It is also hoped the analysis continues to contribute to greater understanding of the impact of this technology and to facilitate more informed decision-making, especially in countries where crop biotechnology is currently not permitted.

This study updates the findings of earlier analysis into the global impact of GM crops since their commercial introduction in 1996 by integrating data and analysis for 2015. Previous analysis by the current authors has been published in various journals, including *AgbioForum* 12 (Brookes and Barfoot, [2009](#)) (2), 184–208, the *International Journal of Biotechnology* (Brookes and Barfoot, [2011](#)), vol 12, 1/2, 1–49 and *GM Crops* 3:4, 265–272 (Brookes and Barfoot, [2012](#)), *GM Crops* 4:1, 1–10 (Brookes and Barfoot, [2013](#)), *GM Crops* 5:1, 65–75 (Brookes and Barfoot, [2014](#)), *GM Crops* 6: 13–46 (Brookes

methodology and analytical procedures in this present discussion are unchanged to allow a direct comparison of the new with earlier data. Readers should however, note that some data presented in this paper are not directly comparable with data presented in previous analysis because the current paper takes into account the availability of new data and analysis (including revisions to data for earlier years).

To save readers of this paper the chore of consulting the past papers for details of the methodology and arguments, these are included in full in this updated paper.

The analysis concentrates on gross farm income effects because these are a primary driver of adoption among farmers (both large commercial and small-scale subsistence). It also quantifies the (net) production impact of the technology. The authors recognize that an economic assessment could examine a broader range of potential impacts (eg, on labor usage, households, local communities and economies).

However, these are not included because undertaking such an exercise would add considerably to the length of the paper and an assessment of wider economic impacts would probably merit a separate assessment in its own right.

RESULTS AND DISCUSSION

HT Crops

The main impact of GM HT (largely tolerant to the broad-spectrum herbicide glyphosate) technology has been to provide more cost effective (less expensive) and easier weed control for farmers. Nevertheless, some users of this technology have also derived higher yields from better weed control (relative to weed control obtained from conventional technology). The magnitude of these impacts varies by country and year, and is mainly due to prevailing costs of different herbicides used in GM HT systems versus conventional alternatives, the mix and amounts of herbicides applied, the cost farmers pay for accessing the GM HT technology and levels of weed problems. The following important factors affecting the level of cost savings achieved in recent years should be noted:

- The mix and amounts of herbicides used on GM HT crops and conventional crops are affected by price and availability of herbicides. Herbicides used include both

protected' chemistry, with availability affected by commercial decisions of suppliers to market or withdraw products from markets and regulation (eg, changes to approval processes). Prices also vary by year and country. For example, in 2008–2009, the average cost associated with the use of GM HT technology globally increased significantly relative to earlier years because of the increase in the global price of glyphosate relative to changes in the price of other herbicides commonly used on conventional crops. This abated in 2010 with a decline in the price of glyphosate back to previous historic trend levels;

- The amount farmers pay for use of the technology varies by country. Pricing of technology (all forms of seed and crop protection technology, not just GM technology) varies according to the level of benefit that farmers are likely to derive from it. In addition, it is influenced by intellectual property rights (patent protection, plant breeders' rights and rules relating to use of farm-saved seed). In countries with weaker intellectual property rights, the cost of the technology tends to be lower than in countries where there are stronger rights. This is examined further in c) below;

- Where GM HT crops (tolerant to glyphosate) have been widely grown, some incidence of weed resistance to glyphosate has occurred and resistance has become a major concern in some regions. This has been attributed to how glyphosate was used; because of its broad-spectrum post-emergence activity, it was often used as the sole method of weed control. This approach to weed control put tremendous selection pressure on weeds and as a result contributed to the evolution of weed populations predominated by resistant individual weeds. It should, however, be noted that there are hundreds of resistant weed species confirmed in the International Survey of Herbicide Resistant Weeds (www.weedscience.com). Worldwide, there are 36 weed species that are currently (accessed February 2017) resistant to glyphosate, compared with 159 weed species resistant to ALS herbicides (eg, chlorimuron ethyl commonly used in conventional soybean crops) and 74 weed species resistant to photosystem II inhibitor herbicides (eg, atrazine commonly used in corn production). In addition, it should be noted that the adoption of GM HT technology has played a major role in facilitating the adoption of no and reduced tillage production techniques in North and South America. This has also probably contributed to the emergence of weeds resistant to herbicides like glyphosate and to weed shifts toward those weed species that are

increasingly being advised to be more proactive and include other herbicides (with different and complementary modes of action) in combination with glyphosate in their weed management systems, even where instances of weed resistance to glyphosate have not been found. This change in weed management emphasis also reflects the broader agenda of developing strategies across all forms of cropping systems to minimise and slow down the potential for weeds developing resistance to existing technology solutions (Norsworthy et al., [2012](#)). At the macro level, these changes have influenced the mix, total amount, cost and overall profile of herbicides applied to GM HT crops. Relative to the conventional alternative, however, the economic impact of the GM HT crop use has continued to offer important advantages for most users. It should also be noted that many of the herbicides used in conventional production systems had significant resistance issues themselves in the mid 1990s. This was one of the reasons why glyphosate tolerant soybeans were rapidly adopted, as glyphosate provided good control of these weeds. If the GM HT technology was no longer delivering net economic benefits, it is likely that farmers around the world would have significantly reduced their adoption of this technology in favor of conventional alternatives. The fact that GM HT global crop adoption levels have not fallen in recent years suggests that farmers must be continuing to derive important economic benefits from using the technology.

These points are further illustrated in the analysis below.

GM HT Soybeans

The average impacts on gross farm level profitability from using this technology are summarised in [Table 1](#). The main farm level gain experienced has been a reduction in the cost of production, mainly through reduced expenditure on weed control (herbicides). Not surprisingly, where yield gains have occurred from improvements in the level of weed control, the average farm income gain has tended to be higher, in countries such as Romania, Mexico and Bolivia. A second generation of GM HT soybeans became available to commercial soybean growers in the US and Canada in 2009. This technology offered the same tolerance to glyphosate as the first generation (and the same cost saving) but with higher yielding potential. The realization of this potential is shown in the higher average gross farm income benefits ([Table 1](#)).

TABLE 1. GM HT soybeans: Summary of average gross farm level income impacts 1996–2015 (\$/hectare).



Download CSV

Display Table

GM HT soybeans have also facilitated the adoption of no tillage production systems, shortening the production cycle. This advantage has enabled many farmers in South America to plant a crop of soybeans immediately after a wheat crop in the same growing season. This second crop, additional to traditional soybean production, has added considerably to farm incomes and to the volumes of soybean production in countries such as Argentina and Paraguay.

Overall, in 2015, GM HT technology in soybeans (excluding second generation ‘Intacta’ soybeans: see below) has boosted gross farm incomes by \$3.82 billion, and since 1996 has delivered \$50 billion of extra farm income. Of the total cumulative farm income gains from using GM HT soybeans, \$23.6 billion (47%) has been due to yield gains/second crop benefits and the balance, 53%, has been due to cost savings.

GM HT and IR (Intacta) Soybeans

This combination of GM herbicide tolerance (to glyphosate) and insect resistance in soybeans was first grown commercially in 2013, in South America. In the first 3 years, the technology was used on approximately 22.3 million hectares and contributed an additional \$2.4 billion to gross farm income of soybean farmers in Argentina, Brazil, Paraguay and Uruguay, through a combination of cost savings (decreased expenditure on herbicides and insecticides) and higher yields (see [Table 1](#)).

GM HT Maize

The adoption of GM HT maize has mainly resulted in lower costs of production, although yield gains from improved weed control have arisen in Argentina, Brazil and the Philippines ([Table 2](#)).

TABLE 2. GM HT maize: Summary of average gross farm income impacts 1996–2015 (\$/hectare).



In 2015, the total global farm income gain from using this technology was \$1.8 billion with the cumulative gain over the period 1996–2015 being \$11.1 billion. Within this, \$3.44 billion (31%) was due to yield gains and the rest derived from lower costs of production.

GM HT Cotton

The use of GM HT cotton delivered a gross farm income gain of about \$116.7 million in 2015. In the 1996–2015 period, the total gross farm income benefit was \$1.77 billion. As with other GM HT traits, these farm income gains have mainly arisen from cost savings (73% of the total gains), although there have been some yield gains in Argentina, Brazil, Mexico and Colombia ([Table 3](#)).

TABLE 3. GM HT cotton summary of average gross farm income impacts 1996–2015 (\$/hectare).



[Download CSV](#)

[Display Table](#)

Other HT Crops

GM HT canola (tolerant to glyphosate or glufosinate) has been grown in Canada, the US, and more recently Australia, while GM HT sugar beet is grown in the US and Canada. The gross farm income impacts associated with the adoption of these technologies are summarised in [Table 4](#). In both cases, the main farm income benefit has derived from yield gains. In 2015, the total global income gain from the adoption of GM HT technology in canola and sugar beet was \$709 million and cumulatively since 1996, it was \$5.89 billion.

TABLE 4. Other GM HT crops summary of average gross farm income impacts 1996–2015 (\$/hectare).



[Download CSV](#)

[Display Table](#)

The main way in which these technologies have impacted on farm incomes has been through lowering the levels of pest damage and hence delivering higher yields (Table 5).

TABLE 5. Average (%) yield gains GM IR cotton and maize 1996–2015.

[Download CSV](#)

[Display Table](#)



The greatest improvement in yields has occurred in developing countries, where conventional methods of pest control have been least effective (eg, reasons such as less well developed extension and advisory services, lack of access to finance to fund use of crop protection application equipment and products), with any cost savings associated with reduced insecticide use being mostly found in developed countries. These effects can be seen in the level of farm income gains that have arisen from the adoption of these technologies, as shown in Table 6.

TABLE 6. GM IR crops: Average gross farm income benefit 1996–2015 (\$/hectare).

[Download CSV](#)

[Display Table](#)



At the aggregate level, the global gross farm income gains from using GM IR maize and cotton in 2015 were \$4.46 billion and \$3.27 billion respectively. Cumulatively since 1996, the gains have been \$46 billion for GM IR maize and \$50.3 billion for GM IR cotton.

Aggregated (Global Level) Impacts

GM crop technology has had a significant positive impact on global gross farm income, which amounted to \$15.4 billion in 2015. This is equivalent to having added 5.2% to the value of global production of the 4 main crops of soybeans, maize, canola and cotton. Since 1996, gross farm incomes have increased by \$167.8 billion.

At the country level, US farmers have been the largest beneficiaries of higher incomes, realizing over \$72.3 billion in extra income between 1996 and 2015. This is not

technology and for several years the GM adoption levels in all 4 US crops have been in excess of 80%. Important farm income benefits (\$39.1 billion) have occurred in South America (Argentina, Bolivia, Brazil, Colombia, Paraguay and Uruguay), mostly from GM technology in soybeans and maize. GM IR cotton has also been responsible for an additional \$38.2 billion additional income for cotton farmers in China and India.

In 2015, 48.7% of the farm income benefits were earned by farmers in developing countries. The vast majority of these gains have been from GM IR cotton and GM HT soybeans. Over the 20 y 1996–2015, the cumulative farm income gain derived by developing country farmers was \$86.1 billion, equal to 51.3% of the total farm income during this period.

The cost to farmers for accessing GM technology, across the 4 main crops, in 2015, was equal to 29% of the total value of technology gains. This is defined as the farm income gains referred to above plus the cost of the technology payable to the seed supply chain. Readers should note that the cost of the technology accrues to the seed supply chain including sellers of seed to farmers, seed multipliers, plant breeders, distributors and the GM technology providers.

In developing countries, the total cost was equal to 20% of total technology gains compared with 36% in developed countries. While circumstances vary between countries, the higher share of total technology gains accounted for by farm income in developing countries relative to developed countries reflects factors such as weaker provision and enforcement of intellectual property rights in developing countries and the higher average level of farm income gain per hectare derived by farmers in developing countries compared with those in developed countries.

Seventy-two per cent of the total income gain over the 20-year period derives from higher yields and second crop soybean gains with 28% from lower costs (mostly on insecticides and herbicides). In terms of the 2 main trait types, insect resistance and herbicide tolerance have accounted for 58% and 42% respectively of the total income gain. The balance of the income gain arising from yield/production gains relative to cost savings is changing as second generation GM crops are increasingly adopted. Thus in 2015 the split of total income gain came 84% from yield/production gains and 16% from cost savings.

Crop Production Effects

Based on the yield impacts used in the direct farm income benefit calculations above and taking account of the second soybean crop facilitation in South America, GM crops have added important volumes to global production of corn, cotton, canola and soybeans since 1996 (Table 7).

TABLE 7. Additional crop production arising from positive yield effects of GM crops.



[Download CSV](#)

[Display Table](#)

The GM IR traits, used in maize and cotton, have accounted for 94.7% of the additional maize production and 98.9% of the additional cotton production. Positive yield impacts from the use of this technology have occurred in all user countries, except for GM IR cotton in Australia where the levels of *Heliothis* sp (boll and bud worm pests) pest control previously obtained with intensive insecticide use were very good. The main benefit and reason for adoption of this technology in Australia has arisen from significant cost savings and the associated environmental gains from reduced insecticide use, when compared with average yields derived from crops using conventional technology (such as application of insecticides and seed treatments). The average yield impact across the total area planted to these traits over the 20 y since 1996 has been +13.1% for maize and +15% for cotton.

As indicated earlier, the primary impact of GM HT technology has been to provide more cost effective (less expensive) and easier weed control, as opposed to improving yields, the improved weed control has, nevertheless, delivered higher yields in some countries. The main source of additional production from this technology has been via the facilitation of no tillage production systems, shortening the production cycle and how it has enabled many farmers in South America to plant a crop of soybeans immediately after a wheat crop in the same growing season. This second crop, additional to traditional soybean production, has added 148 million tonnes to soybean production in Argentina and Paraguay between 1996 and 2015 (accounting for 84.9% of the total GM HT-related additional soybean production). Intacta soybeans added a further 5.84 million tonnes since 2013.

The use of crop biotechnology, by 18 million farmers in 2015, has delivered important farm income benefits over the 20-year period to 2015. The GM IR traits have mostly delivered higher incomes through improved yields in all countries. Many farmers, especially in developed countries, have also benefited from lower costs of production (less expenditure on insecticides). The GM HT technology-driven farm income gains have mostly arisen from reduced costs of production, notably on weed control. In South America, the technology has also facilitated the move away from conventional to low/no-tillage production systems and, by effectively shortening the production cycle for soybeans, enabled many farmers to plant a second crop of soybeans after wheat in the same season. In addition, second generation GM HT soybeans, now widely used in North America, are delivering higher yields, as are the new 'stacked' traited HT and IR soybeans being used in South America since 2013.

In relation to HT crops, over reliance on the use of glyphosate and the lack of crop and herbicide rotation by farmers, in some regions, has contributed to the development of weed resistance. To address this problem and maintain good levels of weed control, farmers have increasingly adopted more integrated weed management strategies incorporating a mix of herbicides, other HT crops and cultural weed control measures (in other words using other herbicides with glyphosate rather than solely relying on glyphosate, using HT crops which are tolerant to other herbicides, such as glufosinate and using cultural practices such as mulching). This has added cost to the GM HT production systems compared with about 10 y ago, although relative to the current conventional alternative, the GM HT technology continues to offer important economic benefits in 2015.

Overall, there is a considerable body of evidence, in peer reviewed literature, and summarised in this paper, that quantifies the positive 'economic' impacts of crop biotechnology. The analysis in this paper therefore provides insights into the reasons why so many farmers around the world have adopted and continue to use the technology. Readers are encouraged to read the peer reviewed papers cited, and the many others who have published on this subject (and listed in the references below) and to draw their own conclusions.

METHODOLOGY

The report is based on extensive analysis of existing farm level impact data for GM crops, much of which can be found in peer reviewed literature. Most of this literature broadly refers to itself as ‘economic impact’ literature and applies farm accounting or partial budget approaches to assess the impact of GM crop technology on revenue, key costs of production (notably cost of seed, weed control, pest control and use of labor) and gross farm income. While primary data for impacts of commercial cultivation were not available for every crop, in every year and for each country, a substantial body of representative research and analysis is available and this has been used as the basis for the analysis presented. In addition, the authors have undertaken their own analysis of the impact of some trait-crop combinations in some countries (notably GM herbicide tolerant (HT) traits in North and South America) based on herbicide usage and cost data.

As indicated in earlier papers, the ‘economic’ impact of this technology at the farm level varies widely, both between and within regions/countries. Therefore, the measurement of impact is considered on a case by case basis in terms of crop and trait combinations and is based on the average performance and impact recorded in different crops by the studies reviewed. Where more than one piece of relevant research (eg, on the impact of using a GM trait on the yield of a crop in one country in a particular year) has been identified, the findings used in this analysis reflect the authors assessment of which research is most likely to be reasonably representative of impact in the country in that year. For example, there are many papers on the impact of GM insect resistant (IR) cotton in India. Few of these are reasonably representative of cotton growing across the country, with many papers based on small scale, local and unrepresentative samples of cotton farmers. Only the reasonably representative research has been drawn on for use in this paper – readers should consult the references to this paper to identify the sources used.

This approach may still both, overstate, or understate, the impact of GM technology for some trait, crop and country combinations, especially in cases where the technology has provided yield enhancements. However, as impact data for every trait, crop, location and year data are not available, the authors have had to extrapolate available impact data from identified studies to years for which no data are available. In addition, if the only studies available took place several years ago, there is a risk that basing current assessments on such comparisons may not adequately reflect the nature of currently available alternative (non GM seed or crop protection) technology. The

weaknesses. To reduce the possibilities of over/understating impact due to these factors, the analysis:

- Directly applies impacts identified from the literature to the years that have been studied. As a result, the impacts used vary in many cases according to the findings of literature covering different years. Examples where such data are available include the impact of GM insect resistant (IR) cotton: in India (see Bennett et al. ([2004](#)); IMRB ([2006](#)) and IMRB ([2007](#))), in Mexico (see Traxler and Godoy-Avila ([2004](#)) and Monsanto Mexico annual monitoring reports submitted to the Ministry of Agriculture in Mexico) and in the US (see Sankala and Blumenthal ([2003](#), [2005](#)), Mullins and Hudson ([2004](#))). Hence, the analysis takes into account variation in the impact of the technology on yield according to its effectiveness in dealing with (annual) fluctuations in pest and weed infestation levels;
- Uses current farm level crop prices and bases any yield impacts on (adjusted – see below) current average yields. This introduces a degree of dynamic analysis that would, otherwise, be missing if constant prices and average yields identified in year-specific studies had been used;
- It includes some changes and updates to the impact assumptions identified in the literature based on new papers, annual consultation with local sources (analysts, industry representatives, databases of crop protection usage and prices) and some ‘own analysis’ of changes in crop protection usage and prices;
- Adjusts downwards the average base yield (in cases where GM technology has been identified as having delivered yield improvements) on which the yield enhancement has been applied. In this way, the impact on total production is not overstated.

Detailed examples of how the methodology has been applied to the calculation of the 2015 y results are presented in [Appendix 1](#). [Appendix 2](#) also provides details of the impacts and assumptions applied and their sources.

Other aspects of the methodology used to estimate the impact on direct farm income are as follows:

- Where stacked traits have been used, the individual trait components were analyzed separately to ensure estimates of all traits were calculated. This is

be) available and used by farmers and there are studies that have assessed trait-specific impacts;

- All values presented are nominal for the year shown and the base currency used is the US dollar. All financial impacts in other currencies have been converted to US dollars at prevailing annual average exchange rates for each year (source: United States Department of Agriculture Economics Research Service);
- The analysis focuses on changes in farm income in each year arising from impact of GM technology on yields, key costs of production (notably seed cost and crop protection expenditure but also impact on costs such as fuel and labor. Inclusion of these costs is, however, more limited than the impacts on seed and crop protection costs because only a few of the papers reviewed have included consideration of such costs in their analysis. In most cases the analysis relates to impact of crop protection and seed cost only, crop quality (eg, improvements in quality arising from less pest damage or lower levels of weed impurities which result in price premia being obtained from buyers) and the scope for facilitating the planting of a second crop in a season (eg, second crop soybeans in Argentina following wheat that would, in the absence of the GM HT seed, probably not have been planted). Thus, the farm income effect measured is essentially a gross margin impact (impact on gross revenue less variable costs of production) rather than a full net cost of production assessment. Through the inclusion of yield impacts and the application of actual (average) farm prices for each year, the analysis also indirectly takes into account the possible impact of GM crop adoption on global crop supply and world prices.

The paper also includes estimates of the production impacts of GM technology at the crop level. These have been aggregated to provide the reader with a global perspective of the broader production impact of the technology. These impacts derive from the yield impacts and the facilitation of additional cropping within a season (notably in relation to soybeans in South America). Details of how these values were calculated (for 2015) are shown in [Appendix 1](#).

DISCLOSURE OF POTENTIAL CONFLICTS OF INTEREST

FUNDING

The authors acknowledge that funding toward the researching of this article was provided by Monsanto. The material presented in this paper is, however, the independent views of the authors – it is a standard condition for all work undertaken by PG Economics that all reports are independently and objectively compiled without influence from funding sponsors.

REFERENCES

1. Bennett R, Ismael Y, Kambhampati U, Morse S. Economic impacts of GM cotton in India. *AgBioforum* 2004; 7(3):96–100.

[Google Scholar](#)

2. Brookes G. The farm level impact of using Bt maize in Spain, ICABR conference paper 2003, Ravello, Italy. Also on www.pgeconomics.co.uk.

[Google Scholar](#)

3. Brookes G. The farm level impact of using Roundup Ready soybeans in Romania. *Agbioforum* 2005; 8(4):235–41 www.agbioforum.org.

[Google Scholar](#)

4. Brookes G. The benefits of adopting GM insect resistant (Bt) maize in the EU: first results from 1998–2006. *Int J Biotechnol* 2008; 10(2/3):148–66;
<https://doi.org/10.1504/IJBT.2008.018351>

[Google Scholar](#)

5. Brookes G, Barfoot P. Global impact of biotech crops: socio-economic effects 1996–2007. *J Agrobiotechnol Management Econom Agbioforum* 2009; 12(2):184–208.

6. Brookes G, Barfoot P. The income and production effects of biotech crops globally 1996–2009. *Int J Biotechnol* 2011; 12(1/2):1–49; <https://doi.org/10.1504/IJBT.2011.042680>

[Google Scholar](#)

7. Brookes G, Barfoot P. The income and production effects of biotech crops globally 1996–2010. *GM Crops Food* 2012; 3(4):265–73; PMID:22750951; <https://doi.org/10.4161/gmcr.20097>

[PubMed](#) | [Google Scholar](#)

8. Brookes G, Barfoot P. The income and production effects of biotech crops globally 1996–2011. *GM Crops* 2013; 4(1):1–10; <https://doi.org/10.4161/gmcr.22748>

[Google Scholar](#)

9. Brookes G, Barfoot P. Economic impact of GM crops: the global income and production effects 1996–2012. *GM Crops Food* 2014; 5(1):65–75; PMID:24637520; <https://doi.org/10.4161/gmcr.28098>

[PubMed](#) | [Google Scholar](#)

10. Brookes G, Barfoot P. Global income and production impacts of using GM crop technology 1996–2014. *GM Crops Food* 2015; 6:13–46; PMID:27116697; <https://doi.org/10.1080/21645698.2015.1022310>

[PubMed](#) | [Web of Science ®](#) | [Google Scholar](#)

11. Brookes G, Barfoot P. Global income and production impacts of using GM crop technology 1996–2015. *GM Crops* 2016; 7:38–77; <https://doi.org/10.1080/21645698.2016.1176817>

[Google Scholar](#)

12. Canola Council of Canada. An agronomic & economic assessment of transgenic canola, 2001, Canola Council, Canada. www.canola-council.org.

[Google Scholar](#)

3. Carpenter J, Gianessi L. Agricultural Biotechnology: updated benefit estimates, 2002, National Centre for Food and Agricultural Policy (NCFAP), Washington, USA.

[Google Scholar](#)

4. CSIRO. The cotton consultants Australia 2005 Bollgard II comparison report, CSIRO, Australia.

[Google Scholar](#)

5. Doyle B. The Performance of Roundup Ready cotton 2001–2002 in the Australian cotton sector, 2003, University of New England, Armidale, Australia.

[Google Scholar](#)

6. Doyle B. The Performance of Ingard and Bollgard II Cotton in Australia during the 2002/2003 and 2003/2004 seasons, 2005, University of New England, Armidale, Australia.

[Google Scholar](#)

7. Elena M. Economic advantages of transgenic cotton in Argentina, INTA, 2006, cited in Trigo and CAP 2006.

[Google Scholar](#)

8. Falck Zepeda J, Sanders A, Trabanino R, Medina O, Batallas-Huacon R. Small 'resource poor' countries taking advantage of the new bio-economy and innovation: the case of insect protected and herbicide tolerant corn in Honduras, 2009, paper presented to the 13th ICABR conference, Ravello, Italy, June 2009.

[Google Scholar](#)

9. Falck Zepeda J, Sanders A, Trabanino R, Medina O, Batallas-Huacon R. Caught between Scylla and Charybdis: impact estimation issues from the early adoption of GM maize in Honduras. *Agbioforum* 2012; 15(2):138–51.

[Google Scholar](#)

20. Fernandez W, Paz R, Zambrano P, Zepeda JF. GM soybeans in Bolivia, 2009, paper presented to the 13th ICABR conference, Ravello, Italy, June 2009.

[Google Scholar](#)

21. Fischer J, Tozer P. Evaluation of the environmental and economic impact of Roundup Ready canola in the Western Australian crop production system, 2009, Curtin University of Technology Technical Report 11/2009.

[Google Scholar](#)

22. Fitt G. Deployment and impact of transgenic Bt cotton in Australia, reported in James C (2001), Global review of commercialised transgenic crops: 2001 feature: Bt cotton, ISAAA.

[Google Scholar](#)

23. Galveo A. Unpublished data on first survey findings of impact of insect resistant corn (first crop) in Brazil, 2009, Celeres, Brazil. www.celeres.co.br

[Google Scholar](#)

24. Galveo A. Farm survey findings of impact of insect resistant corn and herbicide tolerant soybeans in Brazil. 2010, Celeres, Brazil. www.celeres.co.br.

[Google Scholar](#)

25. Galveo A. Farm survey findings of impact of GM crops in Brazil 2012, Celeres, Brazil. www.celeres.co.br.

[Google Scholar](#)

26. Galveo A. Farm survey findings of impact of GM crops in Brazil 2015, Celeres, Brazil. www.celeres.co.br.

[Google Scholar](#)

27. Galveo A. Farm survey findings of impact of insect resistant cotton in Brazil, 2010, 2011, 2012, 2013 and 2015, Celeres, Brazil. www.celeres.co.br

[Google Scholar](#)

28. George Morris Centre. Economic & environmental impacts of the commercial cultivation of glyphosate tolerant soybeans in Ontario, 2004, unpublished report for Monsanto Canada.

[Google Scholar](#)

29. Gomez-Barbero M, Barbel J, Rodriguez-Cerezo E. Adoption and performance of the first GM crop in EU agriculture: Bt maize in Spain. 2008. JRC, EU Commission. Eur 22778. <http://www.jrc.ec.europa.eu>.

[Google Scholar](#)

30. Gonsales L. Harnessing the benefits of biotechnology: the case of Bt corn in the Philippines. 2005, ISBN 971-91904-6-9. Strive Foundation, Laguna, Philippines.

[Google Scholar](#)

31. Gonsales L. Modern Biotechnology and Agriculture: a history of the commercialisation of biotechnology maize in the Philippines, 2009, Strive Foundation, Los Banos, Philippines, ISBN 978-971-91904-8-6.

[Google Scholar](#)

32. Gouse M, Piesse J, Thirtle C. Output & labour effect of GM maize and minimum tillage in a communal area of Kwazulu-Natal. *J Dev Perspect* 2006; 2(2):192-207.

[Google Scholar](#)

33. Gouse M, Pray C, Kirsten J, Schimmelpfennig D. A GM subsistence crop in Africa: the case of Bt white maize in S Africa. *Int J Biotechnol* 2005; 7(1/2/3):84-94; <https://doi.org/10.1504/IJBT.2005.006447>

[Google Scholar](#)

34. Gouse M, Pray C, Kirsten J, Schimmelpfennig D. Three seasons of insect resistant maize in South Africa: have small farmers benefited. *AgBioforum* 2006; 9(1):15-22.

35. Gusta M., Smyth S, Belcher K, Phillips P, Castle D. Economic benefits of GM HT canola for producers. *AgBioForum* 2011; 14(1):1-12.

[Google Scholar](#)

36. Herring R, Rao C. On the 'failure of Bt cotton': analysing a decade of experience. *Economic Political Weekly* 2012; 47(18): 5/5/2012.

[Google Scholar](#)

37. Hudson D. Evaluation of agronomic, environmental, economic and co-existence impacts following the introduction of GM canola in Australia 2010-2012. Paper presented to the 2012 GMCC conference, Lisbon, Portugal, November 2013.

[Google Scholar](#)

38. Hutchison W, Burkness EC, Mitchel PD, Moon RD, Leslie TW, Fleicher SJ, Abrahamson M, Hamilton KL, Steffey KL, Gray ME et al. Area-wide suppression of European Corn Borer with Bt maize reaps savings to non-bt maize growers. *Science* 2010; 330:222-5. www.sciencemag.org; PMID:20929774; <https://doi.org/10.1126/science.1190242>

[PubMed](#)

[Web of Science ®](#)

[Google Scholar](#)

39. IMRB. Socio-economic benefits of Bollgard and product satisfaction (in India), IMRB International, 2006, Mumbai, India.

[Google Scholar](#)

40. IMRB. Socio-economic benefits of Bollgard and product satisfaction (in India), IMRB International, 2007, Mumbai, India.

[Google Scholar](#)

41. Ismael Y, Bennet R, Morse S. Benefits of bt cotton use by smallholder farmers in South Africa. *Agbioforum* 2002; 5(1):1-5.

[Google Scholar](#)

42. James C. Global review of commercialized transgenic crops 2001: feature Bt cotton.

[Google Scholar](#)

43. James C. Global review of commercialized transgenic crops 2002: feature Bt maize, ISAAA No 29, 2003.

[Google Scholar](#)

44. Johnson S, Strom S. Quantification of the impacts on US agriculture of biotechnology-derived crops planted in 2006, 2008. NCFAP, Washington. www.ncfap.org.

[Google Scholar](#)

45. Jon-Joseph AQ, Sprague CL. Weed management in wide-and narrow-row glyphosate resistant sugar beet. *Weed Technol* 2010; 24:523-8; <https://doi.org/10.1614/WT-D-10-00033.1>

[Web of Science ®](#) | [Google Scholar](#)

46. Kathage J, Qaim M. PNAS 2012. Economic impacts and impact dynamics of Bt cotton in India. Available at: <http://www.pnas.org/cgi/doi/10.1073/pnas.1203647109>

[Google Scholar](#)

47. Khan M. Roundup Ready sugar beet in America. *British Sugar Beet Rev Winter* 2008; 76(4):16-9.

[Google Scholar](#)

48. Kirsten J, Gouse M. Bt cotton in South Africa: adoption and the impact on farm incomes amongst small-scale and large-scale farmers, ICABR conference, Ravello, Italy 2002.

[Google Scholar](#)

49. Kniss A. Comparison of conventional and glyphosate resistant sugarbeet the year of commercial introduction in Wyoming. *J Sugar Beet Res* 2010; 47:127-34; <https://doi.org/10.5274/jsbr.47.3.127>

[Google Scholar](#)

50. Kouser S, Qaim M. Valuing financial, health and environmental benefits of Bt cotton in Pakistan. *Agricultural Econom* 2013; 44:323–35; <https://doi.org/10.1111/agec.12014>

[Web of Science ®](#) | [Google Scholar](#)

51. Kouser S, Qaim M. Bt cotton, damage control and optimal levels of pesticide use in Pakistan. *Environ Dev Econom* 2014; 19(06):704–23; <https://doi.org/10.1017/S1355770X1300051X>

[Web of Science ®](#) | [Google Scholar](#)

52. Marra M, Pardey P, Alston J. The pay-offs of agricultural biotechnology: an assessment of the evidence, 2002, International Food Policy Research Institute, Washington, USA.

[Google Scholar](#)

53. MB Agro. Intacta soybeans: An economic view of the benefits of adopting the new technology, 2014 report commissioned by Monsanto Brazil.

[Google Scholar](#)

54. Mendez K, Chaparro Giraldo A, Reyes Moreno G, Silva Castro C. Production cost analysis and use of pesticides in the transgenic and conventional crop in the valley of San Juan (Colombia). *GM Crops* 2011; 2(3):163–8; PMID:22008311; <https://doi.org/10.4161/gmcr.2.3.17591>

[PubMed](#) | [Google Scholar](#)

55. Monsanto Australia. Survey of herbicide tolerant canola licence holders 2008.

[Google Scholar](#)

56. Monsanto Brazil. Farm survey of conventional and Bt cotton growers in Brazil 2007, unpublished.

[Google Scholar](#)

57. Monsanto Romania. Unpublished results of farmer survey amongst soybean growers in 2006 – published in 2007

[Google Scholar](#)

58. Mullins W, Hudson J. Bollgard II versus Bollgard sister line economic comparisons, 2004 Beltwide cotton conferences, San Antonio, USA, Jan 2004.

[Google Scholar](#)

59. Nazli H, Sarker R, Meilke K, Orden D. Economic performance of Bt cotton varieties in Pakistan. Conference paper at the Agricultural and Applied Economics Association 2010 AAEA, CAES and WACA Joint Annual Meeting, Denver, USA.

[Google Scholar](#)

60. Norsworthy JK, et al. Reducing the risk of herbicide resistance: best management practices and recommendations, Weed Science, 2012, Herbicide Resistant Weeds Special Issue, p31-62.

[Google Scholar](#)

61. Parana Department of Agriculture. Cost of production comparison: biotech and conventional soybeans, in USDA GAIN report, 2004, BR4629 of 11 November 2004. www.fas.usad.gov/gainfiles/200411/146118108.pdf.

[Google Scholar](#)

62. Pray C, Hunag J, Hu R, Roselle S. Five years of Bt cotton in China - the benefits continue. Plant J 2002; 31(4):423-30; PMID:12182701; <https://doi.org/10.1046/j.1365-313X.2002.01401.x>

[PubMed](#)

[Web of Science ®](#)

[Google Scholar](#)

63. Qaim M, De Janvry A. Bt cotton in Argentina: analysing adoption and farmers' willingness to pay, 2002, American Agricultural Economics Association Annual Meeting, California.

[Google Scholar](#)

64. Qaim M, De Janvry A. Bt cotton and pesticide use in Argentina: economic and

[Web of Science ®](#) | [Google Scholar](#)

55. Qaim M, Traxler G. Roundup Ready soybeans in Argentina: farm level & aggregate welfare effects. *Agricultural Econom* 2005; 32(1) 73–86.

[Web of Science ®](#) | [Google Scholar](#)

56. Ramon G. Acceptability survey on the 80–20 bag in a bag insect resistance management strategy for Bt corn, 2005, Biotechnology Coalition of the Philippines (BCP).

[Google Scholar](#)

57. Rice M. Transgenic rootworm corn: assessing potential agronomic, economic and environmental benefits, *Plant Health Progress* 2004, 10,094/php-2001-0301-01-RV.

[Google Scholar](#)

58. Riesgo L, Areal F, Rodriguez-Cerezo E. How can specific market demand for non-GM maize affect the profitability of Bt and conventional maize? A case study for the middle Ebro Valley, Spain. *Spanish J Agricultural Res* 2012; 10(4):867–76; <https://doi.org/10.5424/sjar/2012104-448-11>

[Web of Science ®](#) | [Google Scholar](#)

59. Sankala S, Blumenthal E. Impacts on US agriculture of biotechnology-derived crops planted in 2003- an update of eleven case studies, 2003. NCFAP, Washington. www.ncfap.org.

[Google Scholar](#)

60. Sankala S, Blumenthal E. Impacts on US agriculture of biotechnology-derived crops planted in 2005- an update of eleven case studies, 2005 NCFAP, Washington. www.ncfap.org.

[Google Scholar](#)

1. Traxler G, Godoy-Avila S. Transgenic cotton in Mexico. *Agbioforum* 2004; 7(1&2):57-62.

[Google Scholar](#)

2. Trigo E. *Genetically Modified Crops in Argentina agriculture: an opened story*. 2002, Libros del Zorzal, Buenos Aires, Argentina.

[Google Scholar](#)

3. Trigo E, Cap E. *Ten years of GM crops in Argentine Agriculture*, ArgenBio, 2006.
http://argenbio.org/biblioteca/Ten_Years_of_GM_Crops_in_Argentine_Agriculture_02_01_07.pdf

[Google Scholar](#)

4. USDA. *New technologies aiding Burmese cotton farmers*, GAIN report BM 0025 of 14th January 2011.

[Google Scholar](#)

5. Van der Weld W. *Final report on the adoption of GM maize in South Africa for the 2008/09 season*, South African Maize Trust, 2009.

[Google Scholar](#)

6. Vitale J. *Impact of Bollgard II on the Socio Economic and Health Welfare of Smallholder Cotton Farmers in Burkina Faso: Results of the 2009 Field Survey* 14th ICABR conference, Ravello, Italy, June 2010.

[Google Scholar](#)

7. Vitale J, Glick H, Greenplate J, Traore O. *The economic impact of 2nd generation Bt cotton in West Africa: empirical evidence from Burkina Faso*. *Int J Biotechnol* 2008; 10(2/3):167-83; <https://doi.org/10.1504/IJBT.2008.018352>

[Google Scholar](#)

8. Yorobe J. Economics impact of Bt corn in the Philippines, 2004, Paper presented to the 45th PAEDA Convention, Querzon City.

[Google Scholar](#)

9. Zambrano P. Insect resistant cotton in Colombia: impact on farmers, paper presented to the 13th ICABR conference, 2009, Ravello, Italy.

[Google Scholar](#)

Appendix 1: Details of methodology as applied to 2015 farm income calculations

GM IR corn (targeting corn boring pests) 2015

Table

[Download CSV](#)

[Display Table](#)



GM IR maize (targeting maize rootworm) 2015

Table

[Download CSV](#)

[Display Table](#)



GM IR cotton 2015

Table



GM HT soybeans 2015 (excluding second crop soybeans - see separate table)

Table

[Download CSV](#)

[Display Table](#)



GM IR/HT (Intacta) soybeans 2015

Table

[Download CSV](#)

[Display Table](#)



GM HT corn 2015

Table

[Download CSV](#)

[Display Table](#)



GM HT cotton 2015

Table

[Download CSV](#)[Display Table](#)

GM HT canola 2015

Table

[Download CSV](#)[Display Table](#)

GM virus resistant crops 2015

Table

[Download CSV](#)[Display Table](#)

GM herbicide tolerant sugar beet 2015

Table

[Download CSV](#)[Display Table](#)

Second soybean crop benefits: Argentina

An additional farm income benefit that many Argentine soybean growers have derived comes from the additional acres for second cropping of soybeans. This has arisen

technology which has been an important factor facilitating the use of no and reduced tillage production systems. In turn the adoption of low/no tillage production systems has reduced the time required for harvesting and drilling subsequent crops and hence has enabled many Argentine farmers to cultivate 2 crops (wheat followed by soybeans) in one season. As such, the proportion of soybean production in Argentina using no or low tillage methods has increased from 34% in 1996 to 90% by 2005 and has remained at over 90% since then.

Farm level income impact of using GM HT soybeans in Argentina 1996–2015 (2): Second crop soybeans

Table

[Download CSV](#)

[Display Table](#)



Base yields used where GM technology delivers a positive yield gain

To avoid over-stating the positive yield effect of GM technology (where studies have identified such an impact) when applied at a national level, average (national level) yields used have been adjusted downwards (see example below). Production levels based on these adjusted levels were then cross checked with total production values based on reported average yields across the total crop.

Example: GM IR cotton (2015)

Table

[Download CSV](#)

[Display Table](#)



Appendix 2: Impacts, assumptions, rationale and sources for all trait/country combinations

IR corn (resistant to corn boring pests)

Table

Download CSV

Display Table



Readers should note that the assumptions are drawn from the references cited supplemented and updated by industry sources (where the authors have not been able to identify specific studies). This has been particularly of relevance for some of the herbicide tolerant traits more recently adopted in several developing countries. Accordingly, the authors are grateful to industry sources which have provided information on impact, (notably on cost of the technology and impact on costs of crop protection). While this information does not derive from detailed studies, the authors are confident that it is reasonably representative of average impacts; in several cases, information provided from industry sources via personal communications has suggested levels of average impact that are lower than that identified in independent studies. Where this has occurred, the more conservative (industry source) data has been used.

[Download PDF](#)

Related research

People also read

Recommended articles

Cited by
46

Information for

[Authors](#)

[R&D professionals](#)

[Editors](#)

[Librarians](#)

[Societies](#)

Opportunities

[Reprints and e-prints](#)

[Advertising solutions](#)

[Accelerated publication](#)

[Corporate access solutions](#)

Open access

[Overview](#)

[Open journals](#)

[Open Select](#)

[Dove Medical Press](#)

[F1000Research](#)

Help and information

[Help and contact](#)

[Newsroom](#)

[All journals](#)

[Books](#)

Keep up to date

Register to receive personalised research and resources by email



Sign me up



Copyright © 2026 Informa UK Limited [Privacy policy](#)

[Cookies](#) [Terms & conditions](#) [Accessibility](#)

Registered in England & Wales No. 01072954
5 Howick Place | London | SW1P 1WG



Taylor & Francis
by informa